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THE ORES OF COPPER, LEAD, GOLD AND SILVER

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ENGINEERING

BY

CHARLES H. FULTON

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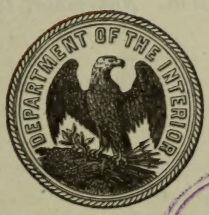

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THE ORES OF COPPER, LEAD, GOLD, AND SILVER.

By Charles H. Fulton.

DEFINITION OF "ORE."

It is difficult to define "ore" so as to include all the conceptions of the term that are and have been prevalent. The term may be given a technical and a scientific definition. The technical definition may be stated as follows: *An ore is a metalliferous mineral, or an aggregate of metalliferous minerals, more or less mixed with gangue, containing metal of commercial importance in such quantity that it may be extracted at a profit by the application of economic and skillful methods of mining and treatment.* This definition restricts the term "ore" to natural mineral products yielding a metal, and makes only such material "ore" from which the metal may be extracted at a profit.

The scientific definition may be stated as follows: *An ore is a metalliferous mineral that contains a metal that has found a recognized application in the arts and industries and occurs in such abundance in nature as to be of commercial importance.* This definition has reference more to the particular mineral, either native metal or compound, as distinct from the mineral aggregate, or mixed mineral mass in which it may occur, and does not bring in the factor of quantity or profit. Thus, galena, the sulphide of lead, and argentite, the sulphide of silver, are ores of lead and silver in the scientific sense, irrespective of the quantity that may be present. In a mineral aggregate consisting of quartz, calcite (carbonate of lime), siderite (carbonate of iron), and a little galena, the last is the "ore" in the scientific sense, and the whole mass or aggregate is the "ore" in the technical sense, if the galena is present in sufficient amount to permit the extraction of lead at a profit. The "gangue" is the matrix of associated minerals in which the valuable mineral occurs, and must of necessity be mined from the ore body to recover the valuable mineral. The nature and the kind of gangue minerals are often important in determining details of ore-dressing operations and metallurgical treatment.

Although the gangue is always mineral in character, it may be divided into two classes—(1) the minerals that make up the vein filling between two more or less distinct rock walls that inclose the vein or ore body, and (2) the rock mass itself throughout which the valuable mineral may be disseminated.

Native metals or alloys, such as gold-silver, platinum and associated metals, and copper, were formerly not considered ore, but this exception is now obsolete. Thus the metallic copper disseminated throughout the amygdaloid rock in the Lake Superior district was formerly designated as "copper rock," but is now properly termed "copper ore." Metallic gold in quartz may be termed "gold quartz," but is also a gold ore. Native metals, particularly gold and platinum, are found also in gravel beds, concentrated therein at some time, ancient or recent, by the action of water currents, the metal having been removed from its original position in some ledge by denudation. These deposits are known as placer deposits, and, as regards gold, the valuable part is designated "gold gravel." This gold gravel is not considered an ore. In order to have the gold or other native metal considered as ore, it must be in place, that is, in its original position in the rock or mineral matrix.

DETERMINATION OF QUANTITY OR ORE IN A GIVEN DEPOSIT.

In all mining operations a most important consideration is the quantity of ore as determined by the size and extent of the ore body or "ore deposit." The value of an ore deposit is determined by the following factors: (1) The size of the ore body—that is, the amount of ore; (2) the metal content of the ore; (3) the net return per ton of ore practicably obtainable—that is, the difference between the gross value and the total cost per ton of mining and treatment.

It is the common experience in American mining that the first factor, the size of the ore body or the amount of ore available, frequently fails to receive proper consideration. At the beginning of a mining operation it is difficult to form a correct idea of the amount of ore that a certain area of ground will yield, and under efficient administration of mining properties considerable prospecting is done by means of shafts, tunnels, drifts, and drill holes, with the object of outlining the extent of the ore body and determining the value of the ore.

On new mining ground, this kind of work is absolutely essential before the erection of a treatment plant or the investment of considerable capital in a permanent mining plant can be considered. On property that is regularly producing ore, exploratory work is necessary in order to establish the presence of ore in sufficient quantity to last for a certain time, at the daily capacity, ahead of immediate

needs. This ore comprises the "ore reserves." The ore reserves in well-administered mines should be sufficient to insure at least a year's supply or more of ore, the extent of the reserves depending upon several factors, chiefly the nature of the occurrence of the ore.

When exploratory work fails to disclose the presence of sufficient ore, an investment of capital is clearly not warranted. As regards a working mine, when the exploratory work fails to reveal new reserves, arrangements are made to close the affairs of the concern as economically as possible.

The question of the "amount of ore" seems extremely simple. In reality it is one that can be answered in most instances only by the most expert work of experienced engineers. The ability to estimate the quantity of ore is frequently assumed by incompetent individuals, actuated by the hope of "what might be" rather than by facts. Such assumptions often lead to large expenditures of capital for a mining and treatment plant, which later on proves to be unwarranted. The vast number of decaying mining and milling plants in many parts of the United States is evidence, in large part, of mistaken judgment as to quantity of ore. Other causes also operate, but their effect is not comparable to the one stated.

There is a strong tendency in recent years to exercise greater conservatism and less hopefulness in reference to the quantity of ore in mining ground. The performance of adequate exploratory work directed toward establishing extensive ore reserves, before the construction of milling and treatment plants, is the policy of modern mining corporations. Many of the larger mines of the country have ore reserves sufficient to last 8 to 10 years or more. There is thus an inclination to definitely outline and expose the ore in a given area before any considerable sum is expended for equipment rather than to trust to good fortune that the ore will be found as work proceeds from year to year. The quantity of ore exposed in some of the larger metal mines, especially in copper mines, is great. This policy aids in giving stability and permanence to the mining industry.

SIZE AND SITUATION OF DEPOSIT AND VALUE OF ORE.

There is a great difference in the size of various ore bodies and in the value of ores. Thus, the Goldfield Consolidated mine in Nevada in the year 1910–11 yielded 266,867 tons of gold ore of the gross value of $40.72 per ton, and in 1910 the Alaska United Gold Mining Co. obtained from the Ready Bullion mine on Douglas Island, Alaska, 232,330 tons, having a gross value of $2.43 per ton. These two mines about represent the extremes of value in large-scale gold-quartz mining in the United States. Similar examples could be given for copper mining.

There is clearly a relationship between the quantity of ore and the value per ton. When the quantity of ore is sufficient to permit its being worked on a relatively large scale the value per ton that will yield a profit can be less than if the ore occurs only in relatively small quantities. Even though the value of the ore in a mineral deposit may be high, the deposit may be so small that its development is not warranted.

The situation of the ore body has an important influence. If the ore is situated on transportation lines, convenient to fuel supply, at a point where labor is plentiful and not high priced, ore of lesser value may be worked at a profit than if the situation is remote from transportation facilities and from the labor market. Thus, advantageous situation is a decided factor in the value of a mineral deposit. Whether a certain deposit can be worked depends, therefore, on the following factors: (1) Metal content of ore, (2) quantity of ore, (3) situation of the deposit, and (4) nature (complexity) of the ore.

A large ore deposit with an average copper content of 10 per cent situated at Butte, Mont., would be considered an extremely valuable property. The same ore body situated in an inaccessible part of the Desert of Sahara would be practically valueless at the present time.

Although a given mineral deposit may not be available now, it may become so later on by the influence of two factors, as follows: (1) A comparatively inaccessible location may become accessible by the extension of transportation facilities and the general advance of civilization, and (2) improvements in methods of mining and ore treatment may make it possible to work lower grade material than has heretofore been possible. Predictions of the exhaustion of metalliferous deposits within a comparatively short time are often erroneously made because the above factors and the probability of new discoveries are not given sufficient weight.

Within the past few years great copper deposits—the so-called "porphyry coppers"—have become available as ore in Arizona, New Mexico, Utah, and Nevada. Ten years or so ago these deposits were practically not considered as being in any way available.

In valuing mines, and in mining reports, the term "average ore value" or "average value of the ore" is frequently used. Although in some ore deposits the valuable metal is rather uniformly distributed, so that each ton mined contains about the same amount of metal, other deposits show a rather wide variation in metal content throughout their extent and the value of the ore as mined varies. In working deposits of this kind a certain minimum metal content that the ore must contain is determined, and material with a lower metal content is not mined but is left in place, or if the conditions make its mining necessary, it is rejected before treatment. Deter-

mination of the lowest grade of ore that can be mined at a profit frequently involves close calculation, as the leaving in place of mineral material may have the effect of increasing costs more than if it is taken out and treated with the rest of the ore. The "average ore value" may thus be defined as the value per ton of the workable part of the ore body, taken as a whole.

No known economic method of metallurgical treatment can recover the whole of the metal content of an ore. There is always a loss, which varies with the metal to be recovered, with the nature of the ore, and with the method of recovery used. Broadly speaking, the recovery is greatest with gold, less with silver, and lowest for copper and lead. In milling processes recoveries of 90 to 96 per cent of the gold in the ore are not infrequent. In smelting processes these figures may be increased. In milling processes the recovery of the silver ranges from 60 to 92 per cent, and more in exceptional instances, whereas in smelting processes it is usually 90 per cent and over, although under certain conditions it may be less. The recovery of copper from ores ranges from 60 to more than 90 per cent, depending on the grade of the ore and whether it is concentrated before being smelted or is smelted direct, as concentration entails a considerable loss. The case of lead ores is similar to that of the copper ores, although the loss of lead in smelting is greater than in the smelting of copper.

These facts must be considered in valuing an ore, as the profit per ton is the difference between the gross value of the ore and the sum of the total treatment cost and the loss per ton. One other factor entering into the value of copper, lead, or silver ores, or ores containing them, is the market price of the metal, which frequently undergoes wide fluctuations. Although gold has a standard value, the price of the other metals varies so that the value of ore of certain metal content may change rather rapidly. An appreciable drop in the price of silver may, for instance, place a producing silver mine in the unprofitable class.

CLASSIFICATION OF COPPER, LEAD, SILVER, AND GOLD ORES.

The accompanying classification of ores is made on a metallurgical basis, the mineral composition of the ore, including the gangue, determining the method of metallurgical treatment. Whether an ore is designated as copper, lead, gold, or silver ore is determined by the metal that predominates in value, but not necessarily in quantity. Although certain ores are plainly copper, lead, gold, or silver ores, others contain two or more of the metals and their proper designation becomes more difficult, because the metallurgical treatment becomes more complex. Thus, although a copper ore contain-

ing gold and silver properly falls into the field of the metallurgy of copper, an ore that contains copper, lead, and gold belongs to the field of lead metallurgy if the lead is to be recovered. The basis adopted for the classification is therefore as follows: The metal first named in the ore type determines the primary method of metallurgical treatment, irrespective of what further treatment may follow in order to separate the metals in the ore. For example, a complex gold ore containing also silver and some lead minerals is treated by gold milling in which concentration is part of the process. The gold milling may include the recovery of some gold by amalgamation with mercury, followed by cyanidation for the recovery of more gold and some silver, followed by the concentration process that recovers the lead and other sulphides, with some gold and silver from the gangue, or worthless part of the ore. The valuable concentrates are then shipped to the lead smelter, which recovers the lead and the remaining gold and silver.

If, however, lead is the predominating metal in the ore even though gold may be present in considerable amount, the ore will be treated directly by the lead smelter.

Gold and silver are readily recovered in both copper and lead smelting, alloying easily with the copper or lead furnace products, from which they may be separated in the subsequent refining operations. Copper and lead are hence collecting agents for gold and silver, which may be recovered from any ore by the processes of lead or copper smelting. Broadly speaking, an ore will be treated by the most economic method available and, hence, gold or silver ores may make part of the furnace charge of lead or copper smelting operations if this treatment happens to be the most economical. Gold and silver ores, however, usually contain large amounts of silica or siliceous rocks as gangue, which may require the addition of much barren flux to the furnace charge, making the smelting costs high, as compared to milling costs. Therefore, the siliceous gold and silver ores, comprising the great mass of these ores, are treated by milling processes distinctive of the metallurgy of gold and silver. In some instances these siliceous ores are necessary to properly balance the mixture of ores composing the furnace charge; then the cost of smelting and the rate on the ores may be such as to make smelting more desirable than milling. As stated, ores are mineral aggregates, and in many ores the valuable mineral is disseminated throughout a mass of valueless minerals. To smelt ores of this kind directly would be costly, and hence a cheap method of separating the waste from the valuable mineral is necessary. This is done by concentration, in which the valuable mineral is concentrated into relatively small bulk and the gangue is eliminated. Con-

centration is commonly carried out by crushing the ore, screening it into a number of different sizes, and washing these in water currents to remove the lighter gangue minerals, only the heavier valuable minerals being recovered. The separation is based on the specific gravity and the size of particles. Other modes of concentration are also practiced, and recently "flotation" methods, in which the valuable heavy sulphide minerals are floated with an air froth, while the gangue sinks, are receiving wide application. Concentration may also be practiced to separate one valuable mineral from another. Lead and copper ores are frequently concentrated before being smelted, and gold, and particularly silver, ores may be treated by a milling process that has a concentration step.

MINERALS CONSTITUTING ORES OF COPPER, LEAD, GOLD, AND SILVER.

The minerals in the accompanying lists are the principal "ore" minerals of copper, lead, gold, and silver ores. They are given in the sequence of their importance. There are many more minerals containing the metals named, but they occur usually in such small quantities as to be unimportant as ore minerals.

The reader should note that the percentages of gold, silver, copper, and lead refer to the pure mineral, not to a mixture of mineral and impurities.

COPPER MINERALS.

1. Native copper, Cu. Contains about 98 per cent copper, and frequently a little silver.

2. Chalcopyrite, $CuFeS_2$. Contains copper 34.5 per cent; iron 30.5 per cent; sulphur 35 per cent.

3. Chalcocite, Cu_2S. Contains copper 79.8 per cent; sulphur 20.2 per cent.

4. Bornite, Cu_3FeS_3. Contains copper 55.5 per cent; iron 16.4 per cent; sulphur 28.1 per cent. Is variable in composition.

5. Cuprite, Cu_2O. Contains copper 88.8 per cent; oxygen 11.2 per cent. Formed by the oxidation of sulphides.

6. Malachite, $Cu_2(OH)_2CO_3$. Contains copper 57.3 per cent; remainder water and carbonic acid. Formed by the action of carbonated waters on other copper minerals or by weathering.

7. Azurite, $Cu_3(OH)_2(CO_3)_2$. Contains copper 55 per cent; remainder water and carbonic acid. Formed in the same manner as malachite.

8. Enargite, Cu_3AsS_4. Contains copper 48.3 per cent; sulphur 32.6 per cent; arsenic 19.1 per cent. Variable in composition; cuprous sulphide may be replaced by the sulphides of zinc and iron, and antimony sulphide may replace arsenic sulphide.

9. Covellite, CuS. Contains copper 66.5 per cent; sulphur 33.5 per cent.

10. Tetrahedrite, $4Cu_2S.Sb_2S_3$. Is highly variable in composition; the cuprous sulphide may in part be replaced by the sulphides of silver, iron, lead, mercury,

or zinc, and the antimony sulphide by arsenic sulphide. Its copper content may vary from 25 to 40 per cent. It is frequently an important ore of silver.

11. Chrysocolla, $CuSiO_3.2H_2O$. Contains copper 36.1 per cent; remainder silica and water. Formed by the action of hot alkaline silicic waters on other copper minerals.

12. Tenorite or melaconite, CuO. Contains copper 79.85 per cent; oxygen 20.15 per cent.

GOLD AND SILVER MINERALS.

1. Native gold, Au. Contains usually some silver. Gold most commonly occurs in this form in ores.

2. Sylvanite (graphic tellurium) $(Au.Ag)Te_2$. Contains gold about 25 per cent; silver 10 to 15 per cent; remainder tellurium. Composition variable.

3. Argentite (silver glance), Ag_2S. Contains silver 87.1 per cent; sulphur, 12.9 per cent. The most common ore mineral of silver.

4. Cerargyrite (horn silver), AgCl. Contains silver 75.3 per cent; chlorine 24.7 per cent. Formed from other silver minerals.

5. Native silver, Ag. Contains chiefly silver, sometimes alloyed with small amounts of other metals, as gold, lead, and copper.

6. Pyrargyrite (dark ruby silver). Ag_3SbS_3. Contains silver 59.9 per cent; antimony 22.3 per cent; sulphur 17.8 per cent. Frequently small amounts of arsenic are present.

7. Proustite (light ruby silver), Ag_3AsS_3. Contains silver 65.4 per cent; arsenic 15.2 per cent; sulphur 19.4 per cent. Sometimes a small amount of antimony is present.

8. Stephanite (brittle silver ore), Ag_5SbS_4. Contains silver 68.5 per cent; antimony 15.2 per cent; sulphur 16.3 per cent.

9. Tetrahedrite, referred to under copper minerals.

10. Calaverite, AuTe. Contains gold 41.5 per cent; tellurium about 57 per cent. Some silver is usually present; variable in composition.

11. Bromyrite, AgBr. Contains silver 57.4 per cent; bromine 42.6 per cent. Formed from other silver minerals.

12. Embolite, Ag(ClBr). Contains 60 to 70 per cent silver; remainder chlorine and bromine. Formed from other silver minerals.

13. Nagyagite (foliated tellurium), $(PbAuSb)(TeS)_2$. Contains gold 7 to 12 per cent. Variable in composition.

14. Petzite $(Au.Ag)_2Te$. Variable in composition. Contains gold up to 25 per cent and silver up to 63 per cent; remainder tellurium.

15. Hessite, Ag_2Te. Variable in composition. Grades into petzite.

16. Polybasite, $9(Ag_2S.Cu_2S)(Sb_2S_3.As_2S_3)$. Contains 62 to 74 per cent silver. Variable in composition. Iron and zinc may in part replace silver, and the antimony and arsenic contents are variable.

LEAD MINERALS.

1. Galena, PbS. Contains lead 86.6 per cent; sulphur 13.4 per cent. Frequently bears silver. The most important ore mineral of lead.

2. Cerussite (white lead ore, carbonate ore), $PbCO_3$. Contains lead 77.5 per cent; remainder carbonic acid and oxygen. Formed by the action of carbonated waters on galena.

3. Anglesite, $PbSO_4$. Contains 68.31 per cent lead; remainder sulphur trioxide and oxygen. Formed by the oxidation of galena.

ZINC MINERALS.

1. Sphalerite (blende, black jack), ZnS. Contains zinc 67 per cent; sulphur 33 per cent. The most important ore mineral of zinc.

2. Smithsonite (dry bone), $ZnCO_3$. Contains zinc 51.9 per cent; remainder carbonic acid and oxygen. Formed by the action of carbonated waters on other zinc minerals.

3. Calamine, $Zn_2SiO_4.H_2O$. Contains zinc 54.2 per cent; remainder silica, water, and oxygen.

4. Franklinite, $(Fe.Mn.Zn).(Fe.Mn)_2O_4$. Contains zinc, about 16 to 20 per cent. Variable in composition.

5. Zincite, ZnO. Contains zinc 80.3 per cent; remainder oxygen.

6. Willemite, Zn_2SiO_4. Contains zinc 58.5 per cent; remainder silica and oxygen.

MINERALS ASSOCIATED WITH ORE MINERALS.

Certain other minerals are commonly associated with the ore minerals of the ores under consideration, for as has already been noted, ores are mineral aggregates. The precious metals are frequently closely associated with certain metallic sulphide minerals. Thus gold is often found in chalcopyrite, in chalcocite, already mentioned, in pyrite, the disulphide of iron, and in arsenopyrite, the sulpho-arsenide of iron. The gold is probably disseminated through these minerals in a very fine state of division as metallic or "native" gold. The mineral is then said to be auriferous, and gold-bearing pyrite is auriferous pyrite. Silver is frequently associated with galena and sphalerite, with some copper minerals, and sometimes with the iron sulphides. It is probable that it is contained as included silver sulphide, argentite, or as a more complex silver mineral. Argentiferous galena is of common occurrence.

The associated minerals may be divided into two kinds—(1) Sulphides, and (2) carbonates, oxides, sulphates, and silicates. The latter may be said to form the gangue minerals. The most common are enumerated below.

SULPHIDES.

1. Pyrite (iron pyrites), FeS_2. This sulphide of iron is a very common and important mineral in ores. It frequently is auriferous, may also contain silver, and sometimes contains enough copper, probably as included chalcopyrite, to be classed as a copper ore. It is a constituent of most ores, often in considerable quantity, and in copper and lead smelting operations is the chief source of the iron required for the slag and matte formed during smelting.

2. Pyrrhotite (magnetic pyrites), Fe_7S_8 (probably). A common sulphide of iron frequently found in ores. It is seldom auriferous, but may be closely associated with copper minerals. Its significance in ores is similar to that of pyrite.

3. Arsenopyrite (mispickel), FeAsS. A sulpho-arsenide of iron. This is a common mineral in ores, and may be auriferous. Arsenic may be an undesirable constituent of ores in a metallurgical operation, but may also be recovered as a by-product, as arsenious oxide, in lead and copper smelting.

4. Stibnite, Sb_2S_3. A sulphide of antimony. Sometimes contains gold and silver. This mineral is not uncommon in ores of lead, gold, and silver, particularly in small amounts disseminated throughout other minerals, as galena. Antimony in any form may influence decidedly the metallurgical treatment of an ore.

Other sulphides and arsenides in ores are marcasite, FeS_2, a disulphide of iron closely related to pyrite, and leucopyrite, $FeAs_2$, an arsenide of iron.

CARBONATES, OXIDES, SULPHATES, AND SILICATES.[a]

1. Quartz, SiO_2, the oxide of silicon, and closely related minerals. This mineral is almost always present in ores and makes up the bulk of many.

2. Calcite, $CaCO_3$. The carbonate of lime. A common mineral in many ores. Ore bodies frequently occur in limestone, chiefly carbonate of lime, or on the contact of other rocks with limestone. In such an ore body lime carbonate may make up a considerable part of the ore bulk.

3. Dolomite, $CaMg(CO_3)_2$. The carbonate of lime and magnesia; variable in composition. The same remarks apply as for limestone.

4. Siderite, $FeCO_3$. The carbonate of iron. A comparatively common mineral in vein deposits.

5. Rhodochrosite, $MnCO_3$. The carbonate of manganese. A not uncommon mineral in some ore deposits.

6. Barite (heavy spar), $BaSO_4$. The sulphate of barium. This mineral is frequently found as a gangue mineral in ore deposits.

7. Fluorite (fluorspar), CaF_2. The fluoride of lime. A common gangue mineral in some ore deposits.

8. Kaolinite (kaolin, clay), $H_4Al_2Si_2O_9$. A hydrated silicate of alumina. Variable in composition; often impure. A decomposition product of certain other minerals, chiefly feldspars, and often found in ores.

Other gangue minerals not so common, although in individual deposits they may be important, are rhodonite, $MnSiO_3$, the silicate of manganese; pyrolusite and psilomelane, oxides of manganese; limonite, $Fe_2(OH)_6.Fe_2O_3$, a hydrated oxide of iron; magnetite, Fe_3O_4, the magnetic oxide of iron; gypsum, $CaSO_4$, calcium sulphate; the pyroxenes, complex metasilicates of lime, magnesia, iron, alumina, and manganese; the amphiboles, similar in composition to the pyroxenes and including hornblende, actinolite, etc.; the micas and chlorite, complex silicates; the feldspar group, orthoclase, albite, oligoclase, anorthite, etc., silicates of alumina, with lime and the alkalies; garnets, complex silicates; alunite, $K(AlO)_3(SO_4)_2 3H_2O$, a hydrated sulphate of alumina and potassa; and other minerals of less frequent occurrence.

In an ore, the mineral composition, aside from the contained ore minerals, may be of importance. In smelting copper ores, the mineral form in which the iron of the ore occurs, for example, whether

[a] Arranged in order of general importance.

as pyrite, or combined as a silicate, or perhaps as magnetite, may decidedly influence the metallurgical treatment. It is often of importance to know whether the silica present in the ore is there as quartz, or in the combined state as a silicate. In the milling of gold and silver ores by the cyanide process, the presence of antimony, copper, or manganese, may cause difficulties if these elements are present in certain mineral form, such as stibnite, malachite, or psilomelane, respectively, but if they be present in stephanite, bornite, and rhodonite, for example, they may have little influence on the treatment. In the cyanidation of silver ores, it is important to know the mineral in which the silver occurs, for the solubility of the various silver minerals in cyanide solution differs greatly; thus, although argentite is readily soluble, proustite is soluble only with difficulty. It follows therefore that a chemical analysis only of an ore is not sufficient as a guide to the proper metallurgical treatment for that ore, but it must be accompanied by the mineral analysis.

In speaking of ores, the terms oxidized and unoxidized or sulphide ores are frequently used. For the copper, lead, zinc, and silver ores the original deposition is chiefly in the form of the sulphide and of sulpho-arsenide, arsenide, or antimonide minerals, accompanied by the commonly found gangue minerals. In the upper part of the deposits, under the influence of the atmosphere and surface waters, certain of the minerals, particularly the sulphides, are subjected to oxidation, with the formation of new mineral compounds, the so-called oxidized minerals. Thus, chalcopyrite, under the influence of oxygenated carbonated waters is changed to limonite, malachite, and azurite; pyrite and pyrrhotite to limonite; argentite, by the action of surface waters containing chlorides, into cerargyrite, etc. Many ore deposits thus have two distinct zones, an upper or oxidized zone, and a lower or sulphide zone, the first being usually the smaller. Its extent is largely dependent upon climatic conditions and topography.

This change in mineral composition in an ore deposit from the surface downward has, of course, an important effect on the proper metallurgical treatment of the ore, and must receive careful consideration in the design of the metallurgical plants that are to treat the ore.

CLASSIFICATION OF ORES PROPER.

The ore classification mentioned above follows.

COPPER ORES.[a]

1. *Ores containing metallic copper.*—Example: Keweenaw Peninsula, Michigan. Native copper in altered amygdaloidal basic lava and interbedded conglomerates. The ores are concentrated and the metallic copper concentrate obtained is smelted.

[a] May contain gold and silver.

2. *Ores containing iron and copper sulphides, and the minerals which are formed by their oxidation.*—Divisible into three subclasses, as follows:

(*a*) Massive iron sulphides, pyrite and pyrrhotite, and copper sulphides. Smelted direct. Examples: Ducktown, Tenn.; Shasta County, Cal.; Mount Lyell, Tasmania; Yak mines, Leadville, Colo.; Rio Tinto, Spain; Sudbury, Canada.

(*b*) Copper and iron sulphide minerals, or the oxidized minerals derived from them, intermixed with a large amount of gangue minerals. Usually in normal fissure veins or in impregnations. Smelted direct, or concentrated and smelted. Oxidized ores may be treated by leaching. Examples: Butte, Mont.; Bingham, Utah; Bisbee, Ariz.

(*c*) Copper and iron sulphide minerals or oxidized copper minerals, disseminated in small grains throughout eruptive or metamorphic rocks (so-called porphyry ores). Concentrated and smelted. Oxidized ores may be subjected to a leaching process. Examples: Bingham, Utah; Ely, Nev.; Santa Rita, N. Mex.; near Globe, Ariz.

ORES CONTAINING LEAD AND COPPER.

Lead and copper minerals, usually some zinc blende and iron sulphide with the gangue minerals, in fissure veins or in impregnations. Frequently contain considerable gold and silver. Concentrated and smelted, or smelted direct. Examples: Silverton, Colo.; Park City, Utah; Georgetown, Colo.

LEAD ORES.[a]

1. *Ores commercially free from precious metal.*—Lead as galena, usually disseminated throughout limestone. Oxidized lead minerals subordinate. Concentrated and smelted. Example: Southeastern Missouri.

2. *Ores containing precious metal.*—Two subclasses, as follows:

(*a*) Chiefly sulphides of iron and lead, or the oxidized minerals derived from them. Smelted direct. Example: Leadville, Colo.

(*b*) Galena, and other sulphides, with gangue minerals in fissure veins or in impregnated deposits. Smelted direct or concentrated and smelted. Examples: Coeur d'Alene, Idaho; Aspen, Colo.

ORES CONTAINING LEAD AND ZINC.

1. *Ores commercially free from precious metals.*—Galena and sphalerite, in large bodies or disseminated in grains through limestone. Concentrated and separated into lead and zinc products, each product smelted separately. Example: Joplin district, Mo.

2. *Ores containing precious metals.*—Galena and sphalerite, and minerals derived by their oxidization; either in veins or similar impregnated deposits or as large masses. Smelted direct or concentrated and separated into lead and zinc products that are smelted separately. Examples: Broken Hill, Australia; Creede, Colo.; Park City, Utah.

GOLD ORES.[b]

1. *Ores containing "free" gold and gold closely associated with sulphides.*—Divisible into three subclasses, as follows:

(*a*) Gold content largely "free" and recoverable by amalgamation. Gangue chiefly quartz, or siliceous rocks; iron sulphides or sulpho-arsenides present not exceeding about 6 per cent of the ore by weight. Treated by amalgamation,

[a] May contain zinc minerals.

[b] Contain silver, but its value is subordinate to that of the gold.

followed by concentration or cyanidation, or both. Examples: Homestake, S. Dak.; Douglas Island, Alaska; Rand mines, South Africa; Grass Valley, Cal.

(*b*) Gold free in part, but chiefly associated closely with iron sulphide minerals. Sulphides, mainly those of iron, may be present in considerable amount. Gangue siliceous. Treated by amalgamation, cyanidation, or by a combination of these processes. Examples: Camp Bird mine, Ouray, Colo.; Morro Velhoe, Minas Geraes, Brazil.

2. *Ores containing gold in chemical combination.*[a]—Some free gold may be present. Gangue siliceous. Iron sulphides may be present in considerable amount. Other sulphides in smaller amounts. Treated by cyanidation, or concentration, or both. Examples: Cripple Creek, Colo.; Goldfield, Nev.; Kalgoorlie, Australia.

GOLD-SILVER ORES.

Silver and gold both present in considerable amount. Silver and gold may be present in complex mineral form. Gangue, largely quartz or siliceous rocks. Treated by cyanidation or concentration or by both methods. Examples: Liberty Bell, San Juan district, Colorado; El Oro, Mexico.

SILVER ORES.

Main value in silver; a little gold always present.

(*a*) Silver in the form of native silver. Sulphides present in small amount. Gangue, calcite, quartz, or siliceous rocks. Treated by concentration, amalgamation, cyanidation, or all methods combined. Examples: Cobalt district, Canada; Batopilas, Mexico.

(*b*) Silver present mainly as argentite or as oxidized silver minerals; gangue, quartz, or siliceous rocks. Sulphides in small amount. Treated by cyanidation, or cyanidation combined with concentration. Examples: Palmarejo mines, Chihuahua, Mexico; Pachuca, Mexico.

(*c*) Silver present in complex silver minerals such as proustite, pyrargerite, tetrahedrite, with some argentite and native silver. Other sulphides, as galena, stibnite, and pyrite, present in small quantities; gangue, limestone, quartz, or siliceous rocks. Treated by cyanidation and concentration combined, or by smelting. Examples: Parral, Mexico; Tonopah, Nev.; Guanajuato, Mexico; Aspen and Creede, Colo.

DESCRIPTIONS OF CLASSIFIED ORE TYPES.

Following are more detailed descriptions of the ore types given in the classification:

ORES CONTAINING METALLIC COPPER.

MICHIGAN.

The copper in the Michigan ores occurs crystallized in part, but chiefly as massive copper, forming casts and fillings in the conglomerates, replacing both the original pebbles (of felsitic porphyrite) and the matrix, and in the amygdaloid lavas (diabase), filling the amygdules or openings formerly occupied by entrapped

[a] Gold in the tellurides, calaverite, and sylvanite.

gases. The ore or "copper rock" is crushed, and the copper concentrated into small bulk, the product being known locally as "mineral." This mineral contains on the average 60 to 75 per cent copper, with an admixture of some of the heavier gangue silicate minerals of the ore, and is smelted and refined into pure copper. The copper contents of the ores as mined range from 0.75 to 1.50 per cent, or from 14 to 30 pounds of copper per ton. In 1914 the copper produced from these ores amounted to 158,009,748 pounds—about 10.1 per cent of the United States production.

MASSIVE IRON SULPHIDES AND COPPER SULPHIDES.

DUCKTOWN, TENN.

The Ducktown ore occurs in lens-shaped bodies in schists, and consists essentially of pyrrhotite and pyrite, which constitute 60 to 75 per cent of the ore. Calcite, quartz, actinolite, tremolite, zoisite, pyroxene, garnet, feldspars, and chlorite are gangue minerals. Small amounts of chalcopyrite, zinc blende, and bornite are present. The copper content of the ore averages about 1.95 per cent. A typical chemical analysis is as follows: Copper, 1.97 per cent; sulphur, 23.7 per cent; silica, 21.9 per cent; iron, 32.6 per cent; alumina, 3.6 per cent; lime, 5.8 per cent; magnesia, 1.9 per cent.

The copper is recovered by pyritic smelting. In this process the mineral condition of the iron and silica is important, and one of the difficulties of metallurgical treatment in the district arises from the fact that a large part of the silica in the ores is already combined in silicate minerals. This district produced in 1914 18,661,112 pounds of copper, or 1.19 per cent of the United States production.

SHASTA COUNTY, CAL.

The ores of the Mammoth and Iron Mountain mines are chiefly massive pyrite, with some chalcopyrite, a little bornite and sphalerite and some quartz. The ores have the following analysis: Copper, 4.06 per cent; silica, 12.4 per cent; iron, 35.4 per cent; zinc, 4.2 per cent; sulphur, 42.7 per cent; alumina, 3.8 per cent; lead, 0.087 per cent; gold, 0.032 ounce per ton; silver, 2.26 ounces per ton.

Other ores in the district are similar, but contain somewhat smaller amounts of pyrite, less copper, more sphalerite, and more silicate minerals. The analysis of Balaklala ore is as follows: Copper, 2.7 per cent; silica, 25.8 per cent; iron, 30.3 per cent; alumina, 4.1 per cent; sulphur, 37.5 per cent; gold and silver, 90 cents per ton. Bully Hill ore contains considerably more sphalerite and chalcocite as well as chalcopyrite, some barite, and silicates of alumina, and

more gold and silver. An average analysis shows 20 per cent sulphur, 23 per cent silica, and 4 per cent copper.

The ores of the district are treated chiefly by pyritic smelting, siliceous ore for the smelting mixture being obtained from local sources, from Idaho, and from Goldfield and Tonopah, Nev.

MOUNT LYELL, TASMANIA.

The Tasmanian ores are of two types, Mount Lyell and North Mount Lyell, which are mixed in such proportion as to make a suitable furnace mixture.

Mount Lyell ore consists in the main of crystalline cupriferous pyrite, small amounts of tetrahedrite and chalcopyrite, a little sphalerite, mixed with a small amount of quartz and barite. The copper content varies, ranging from 4.5 per cent down to 0.75 per cent. A typical average analysis is: Iron, 42.02 per cent; silica, 2.12 per cent; alumina, 1.87 per cent; lead, 0.65 per cent; zinc, 1.30 per cent; sulphur, 48.77 per cent; arsenic, 0.30 per cent; copper, 0.73 per cent; about 2.5 ounces of silver and 0.08 ounce of gold per ton.

North Mount Lyell ore has quartzite and slate as gangue rocks, through which are disseminated the copper minerals, chiefly bornite and some chalcocite and chalcopyrite, and small amounts of pyrite. A typical average analysis is: Silica, 66.6 per cent; iron, 6.80 per cent; alumina, 7.50 per cent; copper, 6.47 per cent; silver, 1.80 ounces per ton; and gold, 0.01 ounce per ton.

LEADVILLE, COLO.

The ores from the Yak mines, Leadville, consist chiefly of crystalline granular cupriferous pyrite, mixed with an appreciable amount of sphalerite, small amounts of chalcopyrite, galena, quartz, calcite, and kaolin. The average composition of the ores is as follows: Iron, 33 to 44 per cent; sulphur, 38 to 45 per cent; alumina and silica, 4 to 20 per cent; zinc, 4 to 8 per cent; copper, 0.5 to 3.5 per cent; lead, up to 0.5 per cent; silver, 2 to 8 ounces per ton. The Yak ores are mixed in proper proportion with highly siliceous ores, which usually contain precious metal, and are smelted by pyritic smelting or are roasted and used for their iron content as flux in lead smelting.

RIO TINTO, SPAIN.[a]

The ore bodies are segregated masses of sulphides in slates and schists associated with eruptive rocks. The ores consist essentially of cupriferous pyrite, the copper occurring mainly as chalcopyrite, chalcocite, and covellite. The amount of gangue minerals, such as

[a] Collins, H. F., Pyrites deposit of Huelva: Mining Mag., vol. 5, 1911, p. 121.

quartz, calcite, and dolomite is very small. The sulphur content of the ore is 45 to 48 per cent, pure pyrite containing 53.3 per cent sulphur. The copper and the sulphur contents of the ore vary, the average copper content being about 2.5 per cent. Ores below 2 per cent copper are sold for the manufacture of sulphuric acid. The copper from the higher grade ores is extracted by both leaching and smelting methods.

SUDBURY, CANADA.

The ores consist chiefly of pyrrhotite, through which is disseminated varying amounts of pentlandite (NiFe)S, a nickel-iron sulphide, and a considerable amount of chalcopyrite. Some pyrite is also present. The gangue consists in the main of the inclosing rocks of the ore body, norite, and of chlorite schist, and in places of quartzite. An average analysis of the ores is: Silica, 10.10 per cent; iron, 44.68 per cent; alumina, 6.85 per cent; lime, 1.19 per cent; magnesia, 1.14 per cent; sulphur, 27.48 per cent; copper, 1.77 per cent; nickel, 5.62 per cent.

The ores are first roasted to expel sulphur and to oxidize the larger part of the iron, and then smelted in the blast furnace and in the reverberatory furnace. Pyritic smelting has been tried with these ores, but has not succeeded, owing probably to the fact that the silica in the gangue is nearly all combined in silicates.

COPPER AND IRON SULPHIDE MINERALS INTERMIXED WITH CONSIDERABLE AMOUNTS OF GANGUE MINERALS.

BUTTE, MONT.

The Butte, Mont., ore bodies are veins in an eruptive rock (monzonite). The ores are divided into two classes—first-class ore, which is smelted direct, and contains more than 3 to 4 per cent copper, and second-class ore, containing about 3 per cent copper, which is concentrated into an enriched product, the concentrate containing 10 to 15 per cent copper.

The copper minerals present in the ore are chalcocite, bornite, enargite, chalcopyrite, and covellite, associated with pyrite and sphalerite, and other sulphides and sulphoarsenides, and sulphoantimonide minerals in small amounts. The gangue minerals are those of the associated rocks, chiefly monzonite. Named in the order of their importance, they are the feldspars, andesine (a complex silicate of soda, alumina, and lime) and orthoclase, quartz, biotite mica, and hornblende. A typical chemical analysis of first-class ore is: Copper, 8.60 per cent; iron, 18.25 per cent; zinc, 0.55 per cent; sulphur, 23.50 per cent; arsenic, 0.70 per cent; lead, trace; alumina, 6.15 per cent; lime, 0.30 per cent; magnesia, trace; silica,

39.30 per cent; silver, 3 ounces, and gold, 0.016 ounce, per ton. An analysis of the second-class ore is: Copper, 3.25 per cent; arsenic, 0.37 per cent; antimony, 0.025 per cent; sulphur, 11.12 per cent; iron, 9.30 per cent; silica, 58.45 per cent; alumina, 11.90 per cent; lime, 0.15 per cent; magnesia, 0.25 per cent; potassa, 2.34 per cent; soda, 0.11 per cent; water, 0.15 per cent above 110° C.[a] An analysis of the concentrate from second-class ore is: Copper, 15.85 per cent; iron, 21.95 per cent; zinc, 0.50 per cent; sulphur, 29.10 per cent; manganese, trace; arsenic and antimony, 0.95 per cent; lead, trace; alumina, 3 per cent; lime, 0.45 per cent; magnesia, trace; silica, 26.50 per cent; silver, 5 ounces, and gold, 0.02 ounce, per ton. The average metal content of the Butte ores, as mined, is about 3.3 per cent copper, 2.5 ounces of silver and 0.010 ounce of gold per ton. Butte production in 1914 was 236,805,845 pounds of copper, or 15.12 per cent of the United States production.

BINGHAM, UTAH.

The ore bodies of the Highland Boy mine, Utah, are lens-shaped, pyritous deposits in limestone. The ore consists of friable pyrite, with which is associated chalcopyrite and some bornite and chalcocite; small amounts of sphalerite and galena are found. The gangue is largely quartz, with some silicate minerals present. The proportion of iron in the ore is 1 to 15 per cent greater than that of silica. A typical analysis of the ore is as follows: Gold, 0.074 ounce per ton; silver, 1 ounce per ton; copper, 2.20 per cent; silica, 25.1 per cent; iron, 28.5 per cent; lime, 3.28 per cent; sulphur, 31.45 per cent; alumina, 1.37 per cent. The ore is roasted and smelted in reverberatory furnaces.

BISBEE, ARIZ.

The Arizona ore bodies (Copper Queen mine) are replacements in limestone. The ores in the upper part of the ore bodies were oxidized ores, consisting of malachite, azurite, cuprite, and native copper as the main ore minerals. The chief ore at present is sulphide ore, although oxidized ore is still mined. The ore minerals in the sulphide ores are pyrite, containing chalcopyrite, chalcocite, and sometimes small quantities of bornite. A little sphalerite is found. The gangue minerals are kaolin (clay), quartz, limonite, chlorite, amphibole, pyroxene, and garnet, the silicate minerals replacing original limestone and the ores containing practically no lime. The ores mined are of three kinds—oxidized ores, sulphide ores, and a low-grade ore containing much clay. These are mixed in such proportion

[a] Goodale, C. W., and Klepinger, J. H., The Great Falls flue system and chimney: Trans. Am. Inst. Min. Eng., vol. 46, p. 568.

as to form, with the addition of some limestone, a mixture that can be smelted direct in blast furnaces, with the production of a 40 per cent copper-iron matte, which is converted to metallic copper by being bessemerized in converters.

COPPER AND IRON SULPHIDE MINERALS DISSEMINATED THROUGHOUT ERUPTIVE OR METAMORPHIC ROCKS.

BINGHAM, UTAH.

The ore consists of porphyry (monzonite), through which are disseminated small grains of pyrite, chalcopyrite, bornite, and chalcocite. The gangue rock, altered monzonite, is composed of the following minerals, stated in the order of the quantity present: Quartz; the feldspars, orthoclase, and plagioclase, partly altered to sericite; hornblende, and biotite. An average analysis of the ore is about as follows: Silica, 66.55 per cent; alumina, 16.75 per cent; iron, 2.44 per cent; lime, 1.27 per cent; soda and potassa, 7.60 per cent; sulphur, 1.54 per cent; copper, 1.52 per cent; remainder, chiefly oxygen, carbonic acid, and water, 1.28 per cent. The copper content of the ore varies between 1.4 and 2 per cent. The combined gold and silver content is valued at about 25 cents or less per ton. The ore is concentrated about 18 to 1, that is, 18 tons of ore make 1 ton of concentrate, the recovery of copper by concentration being about 66.5 per cent. An average analysis of concentrate is: Gold, 0.154 ounce; silver, 1.80 ounces; copper, 24.1 per cent; silica, 16.8 per cent; iron and manganese, 22.2 per cent; sulphur, 32.1 per cent; alumina, 1.70 per cent.

ELY, NEV.

The Nevada ore occurrence at Ely is similar to that at Bingham, Utah. The contents of the ore in metal are—copper, 1.70 per cent to 2 per cent; silver and gold, about 45 cents per ton. About 68 per cent of the copper and 50 per cent of the gold and silver is recovered by the combined operations of concentration and smelting. The ore is concentrated 9.1 into 1, and the concentrate contains about 10.5 per cent copper.

SANTA RITA, N. MEX.

The Santa Rita ore consists of an altered quartz diorite—a rock resembling monzonite, except that the feldspar present is chiefly a plagioclase—through which are disseminated pyrite, copper sulphide minerals, malachite, azurite, and native copper. The ore differs from the Ely and the Bingham ores in the nature of the gangue rock and in the presence of a greater variety of copper minerals. The ore contains about 2 per cent copper and is concentrated into a 27 per cent copper product, which is shipped to a smelter at El Paso, Tex.

NEAR GLOBE, ARIZ.

The ore consists of mineralized schist (a metamorphic rock) and porphyry. The copper minerals disseminated through the rock are chiefly cupriferous pyrite and chalcocite. The copper content worked by one set of mines is about 2.2 per cent, and the ore is concentrated as previously described. An analysis of the concentrate follows: Gold, none; silver, 0.446 ounce; copper, 18.55 per cent; silica, 24.2 per cent; iron and manganese, 22.7 per cent; lime, 0.6 per cent; sulphur, 25.4 per cent; alumina, 3.6 per cent.

In ore bodies worked by other mines the copper content ranges from 2 to 2.5 per cent. About 20 to 22 tons of ore are concentrated into 1 ton of concentrate containing about 40 per cent copper. The extraction by concentration is about 75 per cent.

The "disseminated" ores or "porphyry copper" ores are a development of recent years and are already a source of much copper. Taken as a whole, these mines have estimated ore reserves enough to produce 5,705,000 tons of copper, which with the present milling capacity can be recovered in 25.5 years, or at the rate of 223,710 tons of copper yearly. The total production of copper in the United States for 1914 was 782,854 tons, the production of the porphyry mines being 160,979 tons, or 20.5 per cent.

ORES CONTAINING LEAD AND COPPER AND USUALLY SOME GOLD AND SILVER.

SILVERTON, COLO.

The Silverton ore bodies are veins in eruptive rock. The ore consists of the gangue minerals, quartz, rhodochrosite, barite, and calcite, and the ore minerals, pyrite, chalcopyrite, galena, tetrahedrite, bornite, sphalerite, stibnite, and sometimes native gold. Two classes of ore are mined—(1) high-grade ore, smelted direct, and (2) concentrating ore, which is concentrated about 4½ into 1, and the concentrate smelted. The high-grade ore is divided into two kinds: (*a*) So-called "lead" ore, of which the following is a typical analysis: Gold, 0.18 ounce, and silver, 48 ounces per ton; lead, 38 per cent; and copper, 4.15 per cent; and (*b*) so-called "copper" ores, containing, for example, gold, 1.33 ounces, and silver, 68.1 ounces per ton; lead, 11 per cent; and copper, 8.3 per cent. The concentrate contains 0.5 ounce to 1.5 ounces of gold, and 20 to 30 ounces of silver per ton, and lead, 20 per cent, and copper, 5 per cent. The ores from the different mines vary much in value, concentrating ore containing gold, silver, lead, and copper worth $8 to $20 per ton. High-grade ores and concentrates are treated by lead smelting.

PARK CITY, UTAH.

The Park City ore consists of a quartzite and limestone gangue in which are the following ore minerals: Galena, sphalerite, pyrite, chalcopyrite, and tetrahedrite. About one-third to one-half of the ore is smelted direct; the remainder is concentrated. A typical analysis of high-grade ore is as follows: Gold, 0.046 ounce, and silver, 55.7 ounces per ton; lead, 22.7 per cent; copper, 2.2 per cent; silica, 31.7 per cent; iron and manganese, 6 per cent; lime, 0.5 per cent; zinc, 14.2 per cent; sulphur, 11.8 per cent. The concentrate from the low-grade ore does not contain much copper and has the following typical analysis: Gold, 0.032 ounce, and silver, 34.5 ounces per ton; lead, 33.5 per cent; copper, 0.9 per cent; silica, 10.4 per cent; iron and manganese, 13.20 per cent; lime, 0.8 per cent; zinc, 12.5 per cent; sulphur, 36.0 per cent. Copper-lead ores of similar character are shipped from the Bingham district, Utah; the Coeur d'Alenes, Idaho; and from Georgetown and Silver Plume, Clear Creek County, Colo. Typical analyses of Clear Creek County lead-copper ores are as follows:

Typical analyses of Clear Creek County, Colo., lead-copper ores.

Analysis No.	Gold.	Silver.	Lead.	Copper.	Silica.	Iron and manganese.	Lime.	Zinc.	Sulphur.
	Ounces.	*Ounces.*	*Per cent.*	*Percent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	1.91	12.6	28.7	2.8	30.5	10.00	.....	3.8	14.0
2	.99	26.7	19.4	2.3	30.9	10.00	.....	8.8	17.9

LEAD ORES.[a]

SOUTHEASTERN MISSOURI.

The ore is a dolomitic limestone (lime-magnesia carbonate), through which is disseminated galena and a little pyrite. An average analysis of the ore is: Lead, 5.90 per cent; copper, 0.065 per cent; zinc, 0.82 per cent; sulphur, 2.18 per cent; silica, 4.565 per cent; iron, 3.925 per cent; manganese, 0.465 per cent; lime, 25.30 per cent; magnesia, 14.50 per cent; alumina, 5.75 per cent; carbon dioxide, 36.02 per cent; silver, 0.13 ounce per ton. The ore is concentrated about 12 into 1, and the concentrate smelted. An average analysis of concentrate is: Lead, 63.67 per cent; copper, 0.45 per cent; zinc, 1.70 per cent; sulphur, 13.35 per cent; silica, 0.64 per cent; iron, 3.16 per cent; manganese, 0.33 per cent; lime, 4.98 per cent; magnesia, 2.93 per cent; alumina, 1.29 per cent; carbon dioxide, 7.05 per cent; silver, 1.02 ounces per ton.

[a] Commercially free from the precious metals.

LEAD ORES CONTAINING PRECIOUS METALS.

Many lead ores containing precious metals also contain zinc in considerable quantity, but in the ores under this class it is not saved.

LEADVILLE, COLO., ORES.

Leadville (Colo.) ores may be divided into five classes, as follows: (1) Oxidized silver-lead ores; (2) sulphide silver-lead ores, containing less than about 10 per cent zinc; (3) sulphide silver-lead ores, containing more than 10 per cent zinc; (4) iron sulphide-copper sulphide ores, containing silver and some zinc; (5) other ores not included in the foregoing classes, such as oxides of iron and manganese containing silver, iron sulphide-gold ores and zinc ores. Class 4 has been mentioned under copper ores. The discussion following covers only classes 1 and 2.

OXIDIZED SILVER-LEAD ORES.

Oxidized silver-lead ores, formerly of great importance in the United States, are now nearing exhaustion. They represent the ore bodies derived from the oxidation of sulphides. The ores consist of cerrusite, some anglesite, and a little unaltered galena, in a gangue of hematite, limonite, and manganese oxides, with occasionally some barite. The silver occurs chiefly as cerargyrite. Typical ore from Fryer Hill, Colo., had the following analysis: 30 to 35 per cent iron and manganese, as oxides; silica, 12 to 15 per cent; lead, 21.45 per cent; silver, 65.42 ounces per ton; remainder, oxygen, carbonic acid, and water. These ores were smelted to lead-silver bullion in blast furnaces.

SULPHIDE ORES.

The sulphide ores consist of a mixture of silver-bearing galena, sphalerite, and pyrite in a gangue of dolomitic limestone and an eruptive rock (felsite). The amount of gangue rock in the ore is usually small. The amount of sphalerite varies much. Ores containing less than 10 per cent zinc are treated direct by the lead smelter; those with more than this may be subjected to ore-dressing operations which yield a galena concentrate low in zinc, and a pyrite-sphalerite concentrate low in lead, this latter going to the zinc smelter after a magnetic separation of sphalerite from pyrite. Sulphide ores going direct to the lead smelter have a composition about as follows: Lead, 44 to 50 per cent; zinc, 13 to 12 per cent; iron, 11 to 9.50 per cent; sulphur, 25 to 30 per cent; insoluble residue, chiefly silica, 1 to 2 per cent; silver, 10 to 15 ounces per ton. These

ores are roasted, and the "sinter" or roasted product is smelted in blast furnaces to lead bullion.

ORE CLASSIFICATION BASED ON LEAD CONTENT.

The following is a classification of ores from the lead smelter's point of view, and is based mainly on Leadville, Colo., ores, but is widely used in the West for ores in general:

Ore classification based on lead content.

OXIDES AND CARBONATES.

Designation.	Lead.	Iron.	Insoluble.	Sulphur.	May contain copper and zinc.
Oxides:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Iron oxide ores	<5	45 to 60	2.5 to 17	<1	Yes.
Siliceous dry oxide	<5	6 to 45	17 to 84	<3	Yes.
Siliceous lead oxide	5 to 20	5 to 30	30 to 55	<3	Yes.
Carbonates:					
Dry carbonates	<5	30 to 48	20 to 35	<3	Yes.
Lead carbonates	>5	19 to 46	7 to 30	Up to 5	Yes.

SULPHIDES.

Dry sulphides:					
Siliceous, dry	<5	Up to 15	>50	>3	Yes.
Iron, dry	<5	15 to 30	<50	>3	Yes.
Iron	<5	>30	<30	High.	Yes.
Lead sulphides:					
Siliceous	>5	<30	15 to 50	12 to 20	Yes.
Iron	5 to 15	>30	<15	13 to 35	Yes.
High	>30	5 to 20	1.5 to 5	Up to 26	Yes.

REMARKS ON CLASSIFICATION.

The gold and silver content of the ores may vary widely, from practically no gold or silver to a very high content in these metals. The limiting values of the constituents named are approximate only, and the classification can not be considered rigid. Thus, under dry sulphides, are understood to be included sulphide ores that contain less than 5 per cent lead and in which the sulphide mineral is chiefly iron sulphide.

A sulphide ore from the lead smelter's point of view is one that necessitates roasting as a preliminary operation to smelting. This implies a sulphur content of more than 3 per cent. The dry sulphides may range from mineral mixtures in which the siliceous gangue minerals predominate and the iron sulphides are subordinate in amount to almost pure iron sulphide. Hence, the classification siliceous dry sulphide, iron dry sulphide, and iron sulphide. The first contains only a small amount of sulphide mineral, the second a con-

siderable amount, and the third consists almost entirely of sulphide mineral. Naturally the classes grade into each other and rigid limits for each class can not be set.

Copper may be present in all of the ores mentioned in the classification. Usually the amount of copper is small, but a content as high as 5 or 6 per cent is not uncommon in the so-called lead-copper ores or in the dry sulphides.

The term "dry" applies to ores that contain less than 5 per cent lead. More broadly speaking, the term "dry" should apply to any ore that has insufficient lead or copper to act as a collecting agent for its gold and silver content during smelting, but the lead smelter usually confines the term to ores containing less than 5 per cent lead, with no particular reference to the copper content.

COMPOSITION OF TYPICAL ORES CLASSIFIED ON BASIS OF LEAD CONTENT.

The accompanying table gives the composition of typical ores classified on the basis of lead content:

Composition of typical ores classified on basis of lead content.[a]

Class of ore.	Composition.								
	Gold, per ton.	Silver, per ton	Lead.	Copper.	Insoluble.	True silica.	Iron and manganese.[b]	Zinc.	Sulphur.
	Ounces.	*Ounces.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Iron oxide	None.	9.00	1.00	None.	16.1	.....	48.00	.....	0.4
Siliceous dry oxide	0.48	2.40	1.50	.....	46.4	34.20	32.20	0.40	1.4
Siliceous lead oxide	.38	7.30	16.80	.....	44.6	40.2	17.0	.....	1.5
Dry carbonate	.47	8.60	.....	.....	33.4	30.1	39.2	.....	1.1
Lead carbonate	18.1	14.70	.....	.....	30.7	27.6	24.2	6.00	.7
Siliceous dry sulphide	.75	6.7	4.6	0.90	60.1	54.1	9.00	8.6	12.3
Iron dry sulphide	.25	17.1	2.5	2.90	18.00	16.2	28.00	5.3	High.
Iron sulphide	.04	4.8	2.4	.....	3.30	.....	46.00	6.4	High.
Siliceous lead sulphide	.07	7.5	12.1	.80	22.70	20.4	23.3	7.5	13.1
Iron lead sulphide	.45	13.4	7.1	2.1	14.8	13.4	32.0	2.9	.....
	.02	7.2	7.9	.....	7.3	6.6	39.0	12.4	19.8
High-lead sulphide[c]	.02	19.9	60.1	.30	2.00	1.8	9.1	7.2	High.
	.01	9.0	38.3	.....	3.00	2.1	15.2	13.2	26.8

[a] Ores all taken from Leadville, Colo. [b] Chiefly iron. [c] CaO, 0.6 per cent.

ORES CONTAINING LEAD MINERALS.[a]

COEUR D'ALENE, IDAHO.

The ore deposits are veins in slates, quartzites, and greywackes. The ore minerals are argentiferous galena, pyrite, and blende, and the gangue minerals are chiefly siderite and quartz. The average metal content of the ores taken as a whole is 6 to 10 per cent lead and 3.5 to 7 ounces of silver per ton. The ore is divided into two classes, as follows: (1) High-grade or shipping ore and (2) concentrating

[a] Chiefly argentiferous galena associated with a large amount of gangue in vein deposits.

ore. The ore of the first class comprises one-tenth to one-fourth of the total production. Typical analyses follow:

Analyses of typical high-grade ore from Coeur d'Alene, Idaho.

Sample No.	Gold.	Silver, per ton.	Lead.	Copper.	Silica.	Iron.	Lime.	Zinc.	Sulphur.
		Ounces.	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1.....	None.	37.9	42.4	None.	13.4	15.7	1.1	4.1	11.0
2.....	None.	11.0	41.4	None.	11.0	16.0	1.2	1.3	7.5

The concentrating ore has approximately the following composition: Lead, 5 to 14 per cent; iron, 24 to 27 per cent; silica, 23 to 26 per cent; silver, 4 to 7 ounces per ton. The ratio of concentration is about 8 to 1, and the recovery by concentration varies in different mills from about 76 to 90 per cent of the lead and 50 to 85 per cent of the silver. The following are typical analyses of concentrate:

Analyses of typical concentrate ore from Coeur d'Alene, Idaho.

Sample No.	Gold.	Silver, per ton.	Lead.	Copper.	Silica.	Iron.	Lime.	Zinc.	Sulphur.
		Ounces.	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1.....	None.	44.2	52.8	None.	9.0	13.8	0.9	3.8	12.0
2.....	None.	18.3	52.9	None.	4.6	14.0	1.2	1.5	10.3

The ore from some of the mines contains considerable zinc, and at some of the mills, as the Green-Hill-Cleveland mill at Wallace and the Morning mill at Mullan, certain fine products of the mill are treated by flotation processes for the recovery of both the zinc and the lead sulphides.

ASPEN, COLO.

The ores consist of native silver, argentiferous galena, pyrite, argentiferous barite, sphalerite, and smithsonite in a gangue of limestone and quartz. Formerly much high-grade ore was mined and smelted direct. Now most of the ore must be first concentrated. As an example of ore composition the following analysis is given: Lead, 5 to 9 per cent; silica, 15 to 25 per cent; barite (barium sulphate), 15 to 20 per cent; lime, 8 to 12 per cent; magnesia, 3 to 5 per cent; iron, 8 to 15 per cent; zinc, 3 to 8 per cent; copper, 0.16 per cent; sulphur (exclusive of that combined in the barite), 7 to 10 per cent; silver, 10 to 15 ounces per ton. The concentration is about 4 to 1, typical concentrate having the following analysis: Silver, 5 ounces per ton; lead, 23.5 per cent; copper, 0.1 per cent; silica, 11.9 per cent; iron and manganese, 2.5 per cent; lime, 18.1 per cent; zinc, 1.3 per cent; sulphur, 5.8 per cent.

ORES CONTAINING LEAD AND ZINC.

The complex ores containing lead, zinc, and the precious metals, and sometimes copper, present the ores most difficult for successful metallurgical treatment. Processes for their treatment are discussed in detail in Technical Paper 90 of the Bureau of Mines.[a]

ORES CONTANING LEAD AND ZINC COMMERCIALLY FREE FROM PRECIOUS METALS.

SOUTHWESTERN MISSOURI.

The southeastern Missouri ore contains galena, sphalerite, pyrite, and marcasite in a gangue of limestone and flint, and carries 2 to 3 per cent lead and 3 to 10 per cent zinc. It is concentrated into two products as follows: (1) Galena concentrate, containing 76 to 83 per cent lead, and not more than 2 to 3 per cent iron and zinc; and (2) sphalerite concentrate, containing 62 per cent zinc and not more than 0.2 per cent lead, and up to 4 per cent iron. The galena concentrate is treated by lead smelting and the sphalerite concentrate by zinc smelting.

LEAD-ZINC ORES CONTAINING PRECIOUS METALS.

BROKEN HILL, NEW SOUTH WALES, AUSTRALIA.

The New South Wales ores consist of argentiferous galena and sphalerite and some pyrite in a gangue of quartz, rhodonite, rhodochrosite, garnet, and calcite. At the several mines the composition of the ores differs in the proportion of the sulphide and gangue minerals and in the nature of the occurrence of the sulphides, such as their fineness of dissemination and the intimateness of their mixture, which affect the ore-dressing operations for the separation of zinc and lead. The presence of gangue minerals, such as rhodonite (silicate of manganese), which have a specific gravity approximating that of zinc blende, was the cause of much difficulty in the ordinary water concentration process, and led to the making of a high-grade lead concentrate and a tailings or waste product containing most of the zinc. This waste product by means of the new "flotation" process, is now successfully concentrated into a high-grade zinc product containing little lead. The composition of typical ore follows: Lead, 10 to 15 per cent; zinc, 15 to 25 per cent; silver, 8 to 15 ounces per ton. Such ore is concentrated into a lead product of about the following composition: Lead, 53 per cent; zinc, 10 per cent; silver, 32 ounces per ton; and a zinc product containing, for example, zinc 43 per cent, lead 10 to 12 per cent, silver 10 to 20 ounces per ton.

[a] Lyon, D. A., and others, Metallurgical treatment of the low-grade and complex ores of Utah: Tech. Paper 90, Bureau of Mines, 1915, 40 pp.

The tailings or refuse from the first water concentration are treated by the flotation process and give rise to a zinc product or concentrate of the above composition.

CREEDE, COLO.

The Creede, Colo., ore bodies are veins in eruptive rock (rhyolite). The ore consists of galena, sphalerite, pyrite, and some gold and silver (probably as argentite) intimately mixed and disseminated through a gangue of quartz and altered rhyolite—a highly siliceous eruptive rock. The ore contains about 11 per cent lead, 5 per cent zinc, 2.5 per cent iron, and 60 per cent silica. It is concentrated into two products—(1) a lead concentrate, of which the following is a typical analysis: Gold, 0.31 ounce per ton; silver, 10.9 ounces per ton; lead, 62.1 per cent; copper, 0.1 per cent; silica, 18.2 per cent; iron, 8.6 per cent; zinc, 4.9 per cent; and considerable sulphur; and (2) a zinc concentrate that contains, approximately, 36 to 45 per cent zinc, 2 per cent iron, 13.5 per cent silica. About 1 ton of concentrate is derived from 7 to 8 tons of ore. The one product goes to the lead smelter and the other to the zinc smelter.

PARK CITY, UTAH.

The Park City, Utah (Daly-Judge mine), ore consists of argentiferous sphalerite, galena, and pyrite in a gangue of limestone and quartzite. It has the following average composition: Lead, 10 per cent; zinc, 9 per cent; silver, 7 ounces per ton. The ore is concentrated into two products—(1) galena concentrate, containing lead, 33 per cent; zinc, 7 per cent; iron, 21 per cent; silica, 3 per cent; silver, 18.5 ounces; and gold, 0.06 ounce per ton; (2) zinc concentrate, containing 2 to 4 per cent lead, 25 per cent zinc, 15 per cent iron, 8 per cent silica, 5 ounces of silver, and 0.02 ounce of gold per ton. About 3.75 to 4 tons of ore is concentrated into 1; the amount of the lead concentrate is about twice that of the zinc concentrate.

GOLD ORES.

GOLD PRACTICALLY FREE, ASSOCIATED WITH SOME SULPHIDES, GANGUE QUARTZ, OR SILICEOUS ROCKS.

HOMESTAKE MINE, S. DAK.

The ore body worked by the Homestake mine, S. Dak., lies in a mineralized zone of slates and schists. The ore consists chiefly of chlorite, ferruginous hornblende (cummingtonite), and quartz, small amounts of garnet, mica, and carbonates of lime, and magnesia and iron, as gangue, through which is disseminated pyrite, pyrrhotite, arsenopyrite, and gold largely in the free state. Unoxidized ore

has the following composition: Silica, 54 per cent; iron sulphides, 5.5 per cent; iron oxides, 18.7 per cent; alumina, 5.8 per cent; magnesia, 3.6 per cent; lime, 1.75 per cent; soda, 0.5 per cent; potash, 0.85 per cent; carbonic acid and water, 5.35 per cent. Oxidized surface ore has a similar composition, except that it contains little iron sulphide and more iron oxides and alumina. The average content of the ore in gold is a little less than 0.2 ounce per ton, equivalent to $4 worth, of which 94 per cent is recovered. The gold is alloyed with silver to the extent of 5 parts gold to 1 of silver. It is treated by amalgamation to recover "free gold," after which it is cyanided. The Homestake mine is probably to be considered the world's greatest gold mine.

THE RAND, TRANSVAAL, SOUTH AFRICA.

The Rand ores occur in a quartz pebble conglomerate which is interstratified with quartzites, sandstones, and schists. The conglomerate consists of rounded pebbles one-third of an inch to 6 inches in diameter, which are cemented together by a matrix of silica, iron oxide, and pyrite and chloritic matter. The gold, which occurs chiefly in the free state, is almost entirely in the cementing material and is closely associated with the pyrite. The ore consists essentially of silica, some iron oxide, and pyrite. The value of the gold in the ore is $7 to $10 per ton. The gold is recovered by amalgamation and cyanidation, the recovery being about 90 per cent of the gold content. This is the world's greatest gold field, the production in 1912 being 9,131,558 ounces (valued at $188,749,317), or 40 per cent of the world's production.

DOUGLAS ISLAND, ALASKA.

The Douglas Island, Alaska (Treadwell mines), ore is an altered eruptive rock (albite-diorite) through which is scattered pyrite with some pyrrhotite and free gold. The principal gangue minerals composing the mass of the rock are feldspar, calcite, and quartz, and through these are disseminated the sulphide minerals pyrite and pyrrhotite, with probably some arsenopyrite, constituting about 2 per cent of the ore. Some magnetite is also present. Stibnite, chalcopyrite, molybdenite, sphalerite, and galena are occasionally found but are not of importance. The gold, although largely "free," is closely associated with the sulphides. The ore is milled by amalgamation and concentration, and the concentrate is cyanided. About 48 per cent of the gold is recovered by amalgamation and 46 per cent by concentration and cyanidation. The average value of the ore is a few cents less than $2 per ton. These ores are the lowest grade gold ores in the world successfully mined and milled at a profit, with the

exception of those ores in some smaller mines, such as the Wasp No. 2, in the Black Hills of South Dakota.

GRASS VALLEY, NEVADA COUNTY, CAL.

The ore deposits in Grass Valley, Nevada County, Cal., are quartz veins in eruptive rock (grano-diorite). The ores consist essentially of quartz, through which is disseminated about 2 to 5 per cent of the sulphide minerals, chiefly pyrite, although small quantities of arsenopyrite, galena, chalcopyrite, and sphalerite are also found. The gold occurs chiefly in the free state, although part of it is intimately associated with the sulphides. The ores are treated by amalgamation and concentration; the concentrate is cyanided or smelted. The gold content of the ores differs at the several mines of the district. In the Grass Valley mines an average value is about $10, whereas in the Nevada City mines, it is somewhat lower.

ORES IN WHICH THE GOLD IS PARTLY FREE BUT CHIEFLY ASSOCIATED WITH IRON SULPHIDE MINERALS.

OURAY, COLO.

The ore deposit worked by the Camp Bird mine, Ouray, Colo., is a vein in eruptive rock. The main gangue mineral is quartz, but calcite, rhodonite, and chlorite are also present. The sulphide minerals found, in order of their importance, are pyrite, galena, chalcopyrite, and sphalerite. Some magnetite is present. The gold is in part free and intimately associated with the magnetite and galena and to a lesser extent with the pyrite. The silver present is associated with the galena. Ninety-six per cent of the ore value is in gold. The gold, which occurs as a gold-silver alloy, is 740 fine; the remainder, 260 parts, is chiefly silver. The average composition of the ore as milled is as follows: Silica, 85.20 per cent; galena, 0.50 per cent; chalcopyrite, 0.80 per cent; pyrite, 6.5 per cent; magnetite, 0.5 per cent; sphalerite, 3 per cent; rhodonite, 2.50 per cent; alumina, 1.50 per cent; the ore is milled by amalgamation, concentration, and cyanidation, and 95 per cent of the ore value is extracted. Of this, 64 per cent is recovered by amalgamation, 7 per cent by cyanidation, and 29 per cent by concentration. The concentrate, which is smelted, has the following analysis: Gold, 2.21 ounces per ton; silver, 20.9 ounces per ton; lead, 9.8 per cent; copper, 2.4 per cent; silica, 12.8 per cent; iron and manganese, 20.9 per cent; lime, 3.8 per cent; zinc, 14.5 per cent; and sulphur. The value of the ore in 1911 was about $24 per ton. The Camp Bird mine works a high-grade ore, and although it is now nearing exhaustion, it was one of the great mines of the world.

MORRO VELHOE MINE, MINAS GERAES, BRAZIL.

The ore deposits worked by the Morro Velhoe mine, Minas Geraes, Brazil, are veins in schistose rocks. The average mineralogical composition of the ore is: Pyrrhotite, 28.5 per cent; arsenopyrite, 5.04 per cent; pyrite, 2.5 per cent; chalcopyrite, 0.66 per cent; quartz, 24.10 per cent; siderite, dolomite, and calcite, 39.20 per cent. The chemical analysis is: Silica, 24.10 per cent; iron, 31.47 per cent; arsenic, 2.32 per cent; sulphur, 13.52 per cent; alumina, 3 per cent; manganese dioxide, 1.30 per cent; lime, 3.08 per cent; magnesia, 6.51 per cent; copper, 0.21 per cent; carbon dioxide, etc., 14.49 per cent. The ore is milled by amalgamation and concentration, the concentrate being treated by a special process at the mine. The ore has a value of $10 to $15 per ton, of which about 70 per cent is recovered by amalgamation and 10 to 12 per cent from the concentrate. The high percentage of sulphides in this ore is a noteworthy feature.

ORES CONTAINING GOLD IN CHEMICAL COMBINATION, CHIEFLY AS TELLURIDES.

CRIPPLE CREEK, COLO.

The Cripple Creek, Colo., ore bodies are veins in eruptive rocks. The veins are narrow and the ore as mined contains considerable wall rock, which may be either granite or phonolite. Aside from this included rock, the chief gangue minerals are quartz, fluorite, and dolomite. Gold occurs as the tellurides, calverite, sylvanite, and krennerite, stated in order of their importance. With the tellurides are associated pyrite and sphalerite as the chief sulphide minerals, but they are probably not gold bearing. Galena, stibnite, tetrahedrite, and molybdenite in small amounts are found. The ores contain a small quantity of silver, which is a constituent of the tellurides. The average chemical composition of the ore is as follows: Silica, 57 per cent; alumina, 20 per cent; iron, 4 per cent; magnesia, 0.8 per cent; lime, 1.50 per cent; alkalies (soda and potash), 10.5 per cent; sulphur, 2.5 per cent; very small quantities of zinc, copper, arsenic, lead, and molybdenum. The grade of the ores varies much from high-grade smelting ore to low-grade milling ore. Old dumps containing ore valued at $3.50 to $3.80 per ton are successfully treated by cyanidation. The average value of the ore mined in the district is probably about $19 per ton. The Cripple Creek district is one of the world's great gold fields.

GOLDFIELD, NEV.

The Goldfield (Nev.) ore deposits are veins in eruptive rock (dacite). The ore is essentially a silicified dacite consisting of 50 to 75 per cent quartz; kaolinite and alunite (a hydrated sulphate

of alumina and potassa), and 5 to 7 per cent of pyrite. Minerals present in small amount, but closely associated with the gold, are bismuthinite and tetrahedrite. A small amount of chalcopyrite is found. The gold occurs both free and closely associated with other minerals and perhaps in the form of tellurides, possibly calaverite and other rarer telluride minerals. The gold is accompanied by some silver, the ratio being about 65 to 1. The following is a typical analysis of very high-grade ore: Silica, 77.08 per cent; alumina, 4.96 per cent; iron, 3.63 per cent; calcium, magnesium, and manganese oxides, 0.92 per cent; potassa, 1.42 per cent; soda, 3.22 per cent; copper, 0.37 per cent; bismuth, 1 per cent; tellurium, 0.14 per cent; sulphur, 4.80 per cent; gold, 131.24 ounces; and silver, 20.42 ounces per ton. Most of the ore of the district is treated by combined amalgamation, cyanidation, and concentration, the ore of the Goldfield Consolidated mine, the largest producer of the district, having an average value of $19.77 during 1912. Following are analyses of typical higher grade ores as shipped to smelters:

Analyses of typical high-grade ores from Goldfield Consolidated mine.

Analysis No.	Gold.	Silver.	Silica.	Iron.	Sulphur.
	Ounces.	*Ounces*	*P. ct.*	*P. ct.*	*P. ct.*
1	5.40	34.61	67.3	3.4	1.4
2	5.21	5.42	45.8	5.6	4.8

KALGOORLIE, AUSTRALIA.

The Kalgoorlie (Australia) ore bodies are veins in chloritic schist. The gangue of the ore, aside from included country rock, is chiefly quartz, calcite, siderite, and dolomite, through which is scattered considerable pyrite. The gold occurs chiefly as the tellurides, calaverite, sylvanite, and petzite, but some free gold is found. Some telluride of mercury occurs. The following analysis represents typical ore: Silica, 60.6 per cent; alumina, 5.75 per cent; pyrite, 5.32 per cent; carbonate of lime, 11.19 per cent; carbonate of magnesia, 5.29 per cent; carbonate of iron, 10.23 per cent; alkalies (by difference), 1.62 per cent. The value of the ore varies from about $7 to $17 per ton at the different mines, with an average value of about $10 to $11 for the district. The ores are treated by cyanidation. This district is the great gold field of Australia.

GOLD-SILVER ORES.[a]

LIBERTY BELL MINE, COLO.

The ore body worked by the Liberty Bell mine, Colo., in a vein in eruptive rock (andesitic breccia). The mineralogical composition

[a] Both silver and gold present in considerable amount.

of the ore is as follows: Quartz and clay, 84.44 per cent; calcite, 9.45 per cent; apatite, 0.20 per cent; pyrite, 3.60 per cent; arsenopyrite, 0.24 per cent; bornite and chalcopyrite, 0.15 to 0.23 per cent; some manganese oxides. The gold occurs free and closely associated with sulphides. The silver is present as argentite and as free silver and in more complex mineral form. Galena, sphalerite, and tetrahedrite occur only occasionally. The value of the ore is about $8.35 per ton, the ore containing 0.31 ounce of gold and 3.45 ounces of silver per ton. The ore is treated by amalgamation, concentration, and cyanidation. Typical concentrate has the following analysis: Gold, 1.43 ounces per ton; silver, 28.8 ounces per ton; silica, 9.4 per cent; iron and manganese, 38.8 per cent; lime, 1 per cent; zinc, 2.6 per cent; sulphur, 31.2 per cent.

LAS DOS ESTRELLAS, NEAR EL ORO, MEXICO.

The ore bodies at Las Dos Estrellas, near El Oro, Mexico, are veins in shales associated with eruptives (andesite). The ores milled are both oxidized and unoxidized, and consist of quartz, altered shale, and andesite. In the unoxidized ores considerable pyrite is present. The gold occurs in the free state, but very finely divided; the silver occurs as argentite in the sulphide ores and as chloride and metallic silver in the oxidized ores. Zinc, lead, and copper minerals are practically absent. The ore as mined contains about 0.4 ounce of gold and 7 to 8 ounces of silver per ton. It is treated by cyanidation. The mines in the vicinity of El Oro are among the most important mines in Mexico and rank with the world's greatest gold mines.

SILVER ORES.

ORES CONTAINING CHIEFLY NATIVE SILVER.

BATOPILAS, MEXICO.

The Batopilas (Mexico) ore deposits are veins in eruptive rock (diorite). The ore is essentially native silver in calcite as a gangue mineral. The silver in the low-grade ores is very finely disseminated throughout the gangue, most of it being of such fineness that it will pass a 40 to 60 mesh screen. Silver is found also in large masses and is unusually pure. In the low-grade ores the native silver is associated with argentite, pyrite, galena, and sphalerite. Silver minerals such as cerargyrite were found only in the upper oxidized part of the vein. The low-grade ore and the tailings from rich ore are treated by concentration, amalgamation, and cyanidation.

COBALT, CANADA.

The Cobalt, Canada, ore bodies are veins in a complex of metamorphic rocks and Huronian conglomerate associated with an erup-

tive rock (diabase). The gangue of the ores is largely calcite, with fragments of wall rock and some quartz. The silver occurs chiefly as native silver, frequently in large masses and nuggets, but also in small grains, rather finely disseminated. Silver minerals, as dycrasite (antimonial silver, Ag_3Sb), argentite, and pyrargerite, are also found, but are subordinate in importance. Associated with the silver are the minerals smaltite (cobalt-nickel arsenide—$CoNiAs_2$) and niccolite (nickel arsenide, NiAs) and other cobalt-nickel minerals. The nickel-cobalt content of the ores is not as yet of much commercial importance, but will probably become so. The value of the ores varies much, as they range from high grade to medium grade. Ores containing more than 100 ounces of silver per ton are milled or shipped and smelted, and ores with a lower metal content are first concentrated. Typical shipping ore has the following analyses:

Analyses of typical shipping ore from deposits at Cobalt, Canada.

Analysis.	Silver per ton.	Copper.	Silica.	Iron.	Lime.	Arsenic.	Sulphur.	Cobalt and nickel.
No.:	*Ounces.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
1....	630.3	0.1	6.8	7.8	7.8	34.9	2.4	Considerable.
2....	187.6	.1	58.1	6.2	3.8	1.2	4.0	Do.

The average silver content of concentrating ore in 1910 was about 27 ounces per ton. The concentrate is shipped, and the tailings from concentration at a number of mills are treated by cyanidation for a further recovery of silver. Cobalt is the world's greatest silver district.

ORES CONTAINING SILVER CHIEFLY AS ARGENTITE.

PACHUCA, MEXICO.

The Pachuca, Mexico, ore bodies are veins in eruptive rocks (andesite). The gangue of the ores is essentially quartz, although in some mines of the district rhodonite is an important gangue mineral. Some clay occurs, and in places a little calcite. Practically all ores now mined are unoxidized. The sulphide minerals are present only in small amount and consist of pyrite, a little galena, and chalcopyrite. The great Santa Gertrudis vein is remarkably free from sulphides other than argentite, the form in which practically all the silver occurs. The ratio of silver to gold is about 200 to 1 by weight. In some of the mines a little native silver is found with the argentite. Other silver minerals are comparatively rare. The ores of the Santa Gertrudis range in value from $10 to $20 per ton. The Pachuca district is one of the great silver districts of Mexico. The ores are treated by cyanidation.

CHIHUAHUA, MEXICO.

The ore bodies at Chihuahua, Mexico (Palmarejo mines), are veins in eruptive rock. The gangue is largely silicious, included rock and quartz with some oxide of manganese and calcite, through which is disseminated a small percentage of pyrite and the silver minerals. The chief silver mineral is argentite, though some stephanite and cerargyrite are present. Very small quantities of antimony, arsenic, bismuth, copper, and zinc are found. The ore contains about $4 worth of gold and 30 ounces of silver per ton. It is treated by concentration and cyanidation.

SILVER PRESENT IN PART AS COMPLEX SILVER MINERALS.[a]

PARRAL, CHIHUAHUA, MEXICO (VETA COLORADO).

The ore bodies at Parral, Chihuahua, Mexico, are quartz veins in shale or limestone associated with eruptive rocks (quartz-andesite dikes). The gangue is quartz through which is disseminated 2 to 3 per cent of pyrite, and galena and zinc blende up to 1.5 per cent each, and the silver minerals, chiefly argentite, with a small amount of cerargyrite. A very small amount of copper is present. Gold is practically absent. The ore is treated by concentration and cyanidation.

GUANAJUATO, MEXICO (VETA MADRE).

The ore body at Guanajuato, Mexico, is a large vein in a calcareous agglomerate and other detrital rocks, associated with eruptives (rhyolite, andesite, and granite). The gangue consists of quartz, some calcite, and fragments of country rock cemented by silica and impregnated with pyrrhotite and pyrite. The silver minerals are chiefly argentite, stephanite, and pyrargerite, and some proustite and polybasite. Galena, chalcopyrite, and sphalerite are rarely found. The amount of gold is about 0.005 that of the silver present, by weight. The analysis of the milling ore is as follows: Insoluble (silica), 85 per cent; iron, 6 per cent; sulphur, 2.5 per cent; lime, 2 per cent. The ore contains about 14 ounces of silver and 0.06 ounce of gold per ton. It is treated by concentration and cyanidation. Guanajuato is one of the oldest silver-mining districts in Mexico, mining there having been begun shortly after the Spanish conquest. The district has produced enormous quantities of silver.

TONAPAH, NEV.

The Tonopah (Nev.) ore bodies are veins in an eruptive rock (andesite). The gangue of the ore consists chiefly of quartz, with adularia (potash feldspar), muscovite, and a small amount of car-

[a] Or associated with appreciable amounts of argentiferous galena or sphalerite.

bonates of lime and magnesia. The sulphide minerals are chiefly those of silver, argentite, polybasite, stephanite, and pyrargerite. Pyrite is present only in very small amount. Galena, zinc blende, and chalcopyrite are found in insignificant quantities only. Selenium occurs in the ores, probably in part as a selenide of silver. The ratio of silver to gold by weight is 90 to 1. The average value of the ore is about $20 per ton. The greater part of it is treated by concentration and cyanidation, and some of the higher grade ore is shipped to smelters. The following are typical analyses of smelting ore:

Typical analyses of smelting ore from Tonopah, Nev.

Analysis No.	Gold, per ton.	Silver, per ton.	Lead.	Copper.	Silica.	Iron.	Sulphur.
	Ounces.	*Ounces.*			*Per cent.*	*Per cent.*	*Per cent.*
1.....	0.91	88.17	None..	None....	78.9	1.8	1.2
2.....	.57	58.21	None..	None....	84.0	1.8	1.1

ASPEN, COLO.

Certain mines at Aspen, Colo., produce a silver ore with a limestone gangue which has considerable value as a flux in lead smelting. The following are typical analyses of this ore:

Typical analyses of ore from Aspen, Colo.

Analysis No.	Gold.	Silver, per ton.	Lead.	Copper.	Silica.	Iron and manganese.	Lime.	Zinc.	Sulphur.
		Ounces.	*Per ct.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*	*Per cent.*
1.....	None.	7.4	0.30	None.	4.2	1.3	43.4	0.3	0.8
2.....	None.	7.1	.20	None.	7.0	1.7	37.9	.6	.6

CREEDE, COLO.

The Commodore mine at Creede, Colo., produces a highly siliceous silver ore containing some lead that is useful to the lead smelter in concentrating lead-copper matte. The following is a typical analysis of this ore: Gold 0.02 ounce and silver 23.5 ounces per ton; lead, 2 per cent; copper, none; insoluble, 82.6 per cent; true silica, 71.8 per cent; iron and manganese, 4.2 per cent; lime, 0.3 per cent; zinc, 0.3 per cent; sulphur, 2.1 per cent.

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